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DESIGN AND EVALUATION OF A THREE-ZONE THERMAL MANIKIN HEAD

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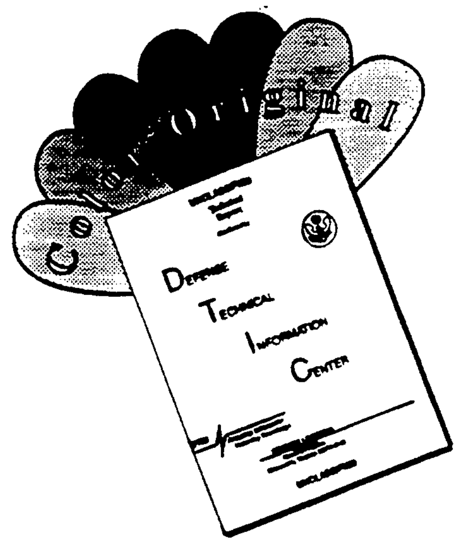

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DESIGN AND EVALUATION OF A THREE-ZONE THERMAL MANIKIN HEAD

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Executive Summary

A three-zone thermal manikin head was constructed to study the effect of insulation and wind on heat transfer from the face and scalp. Unlike the heads of other thermal manikins, which have only one heat transfer zone, the three-zone head can measure the effect of wind on heat transfer from specific areas. It can be used to determine the thermal insulation that hats, helmets or face masks add to the areas they cover. Single-zone thermal manikin heads can only measure the effective thermal resistance of the whole head.

The device is based on a rigid polyurethane foam headform. Its low heat capacity allows it to come to steady state more quickly than if it had been made with a thick shell of aluminum or copper. It has independent zones corresponding to the face and the scalp as well as a small zone corresponding to the forehead and ears. A zone corresponding to the neck is used as a guard heater to minimize heat loss through the base of the device from the other sections. Each zone has a heater to supply heat to the surface in an approximately uniform pattern, and a distributed temperature sensor that provides a good estimate of the mean surface temperature. Multiple layers of aluminum foil tape were used to distribute the heat and to ensure a more uniform surface temperature. A computer controls, monitors and averages the power required to maintain a steady state at the desired surface temperature. Heat transfer coefficients are calculated from the surface area, the steady state power and the difference between air and surface temperature.

A series of measurements of heat transfer to moving air was carried out with the thermal model in the DCIEM climatic suite. Overall convective heat transfer coefficients at a range of windspeeds fell between those of the head of the CORD thermal manikin and that of an early version of USARIEM's Copper Man. Whole head heat transfer coefficients measured with the three-zone head also compare favourably with the few available published estimates of heat transfer from the heads of human subjects.

The separate contributions of radiation and forced convection to total heat transfer were determined. Natural convection is shown to be insignificant at wind speeds above 1 m/s. The measurements yielded an equation that relates convective heat transfer from a head to wind speed, at winds between 1 and 7.3 m/s.

Abstract

A thermal model of a human head was constructed that has three zones: the scalp, face and a small forehead/ears zone. The surface temperature and heat loss from each zone are individually controlled and monitored by a computer. Because it has independent zones, the three-zone thermal manikin head can provide more accurate measurements of the thermal insulation of hats, helmets and face masks. Single-zone thermal manikin heads measure the effective thermal resistance of the whole head, which usually includes large areas not covered by the item in question.

Heat transfer from the entire manikin head was measured in a wind tunnel at wind speeds up to 7.3 m/s (26 km/h). The results compared favourably with whole head heat transfer from the head segment of other thermal manikins and from the human head. An equation was derived to describe the effect of wind on heat loss. The radiative heat transfer coefficient was also determined.

Introduction

Experts have long suspected that the sensation of wind chill might be mostly due to the cooling effect of wind on the bare face and almost everyone knows that a significant fraction of the body heat loss can occur from the head in cold weather. In hot weather, fanning the face is almost a reflex action. However, despite the importance of head and facial cooling to the comfort of individuals in cold or heat, the effect of wind speed on heat transfer from the face or head has not been fully investigated. To address this deficiency, we constructed a thermal model of the human head that has independent zones corresponding to the face and the scalp and a small zone that corresponds to the forehead and ears.

The device also has an immediate practical application as a thermal manikin head with which the actual thermal insulation values of headwear and facewear can be measured. Single-zone thermal manikin heads can not measure the insulation that an item adds to the area it covers; they measure the insulation of the whole head, which often includes large areas that are not covered by the article being assessed.

Design

The three-zone thermal manikin head is based on a rigid polyurethane foam headform. The largest circumference of the headform, around the brow-ridge and the back of the head, is 61 cm. The longest dimension between the point of the chin and the crown of the head is 27 cm. The maximum width of the head is 16.2 cm. The circumference of the neck at collar level is 41.6 cm. Ears were eliminated to simplify construction.

The foam is relatively strong and has a low heat capacity, which helps it to come to steady state more quickly than if it had been made with a thick shell of aluminum or copper. Each zone has a heater to supply heat to the surface approximately uniformly and a distributed temperature sensor that provides a good estimate of the mean surface temperature.

The surface of the headform was first covered with multiple layers of aluminum foil tape (2900 PG Aluminum Foil Duct Tape, Eastern Refrigeration, Markham, Ontario). When applied smoothly, five layers of this tape has a thickness of approximately 0.5 millimeters. Areas corresponding to the scalp, face, neck and forehead/ears were separated by thermal breaks that were approximately 8 mm wide. The breaks were later filled with modeling clay to smooth the surface.

A heating circuit of 30 gauge constantan wire was applied to the surface of each division of the headform. Constantan has a reasonably high electrical resistance that does not change significantly with temperature. The wire was

laid down in a pattern that snaked back and forth across the surface, covering it more or less uniformly. Spaces of 5 to 10 millimetres separated "back" and "forth". This wire heats the entire surface relatively evenly, reducing the need for a thick, thermally conductive metal shell. Small strips of aluminum tape were used to hold the wire to the surface while the pattern of wire was being applied. The surface was then covered with another five to ten overlapping layers of adhesive-backed aluminum foil tape to further distribute the heat. The electrical resistances of the heating circuits are listed in Table 1.

TABLE 1
Characteristics of Heat Transfer Zones

Zone	Heater Resistance [Ω] @ 36°C	Area [m^2]
Scalp	40.26	0.0522
Forehead	25.66	0.0160
Face	34.85	0.0367
Neck	39.48	0.0405
Scalp+Face + Forehead		0.105

The surfaces of each zone were then covered with another circuit of 30 gauge copper wire that snaked roughly at right angles to the heating wires. These sensor wires were also covered by several layers of aluminum tape. The surface temperature was measured by measuring the electrical resistance of this circuit. The sensor circuits had electrical resistances of 1 to 2 Ω. Because copper has a much higher temperature coefficient of electrical resistance than constantan, the electrical resistance of these sensor circuits changes measurably with temperature. Once the resistance of each circuit had been calibrated against its temperature, the mean surface temperature of each zone could be determined. A precision of ± 0.02 °C could be obtained by measuring electrical resistance to the nearest 10 μΩ.

Calibration of Surface Temperature Sensors

As it was initially intended that the surface temperature of the device would be set at some temperature between 33 °C to 36 °C, the sensor circuits were calibrated in an environmental chamber at a series of temperatures between 20 °C and 50 °C. The thermal manikin head was encased in 5 cm of polyester batting to ensure a uniform surface temperature and to damp any cycling of the chamber temperature. The head and chamber were allowed at

least four hours to reach a steady state after each adjustment of chamber temperature. Surface temperature was measured with a copper-constantan thermocouple. Its cold junction was maintained at 0 °C ± 0.02 °C by a Kaye Instruments Ice Point Reference. A Hewlett-Packard 3458A Multimeter, which can measure the resistance to the nearest 1 $\mu\Omega$, was used in a four-wire mode to measure the resistance of each circuit. The four-wire mode eliminates the electrical resistance of the lead wires. Linear regression equations were derived from this data to relate the resistance of each circuit to its temperature.

Measurement of Surface Areas

As the heat transfer zones are not simple geometrical shapes, a two-stage process was devised to measure their surface areas. Each zone was covered with several layers of cloth-backed, black library tape, trimmed to fit. The tape was then peeled off, with care being taken to avoid stretching it. The tape replicas were dusted with chalk to reduce tackiness and then cut so that they would lie approximately flat. This resulted in a set of very complex two-dimensional shapes made of tape of varying thickness. These shapes were then photocopied, and the black image was carefully cut out of the paper. The mass of each paper replica was determined to 1 mg on an electronic scale and compared to the mass of a full sheet of exposed photocopy paper. The mass/unit area of exposed photocopy paper varied by less than 0.4%. The ratio of the masses multiplied by the area of the full sheet gave the area of the two dimensional paper replica within a few percent. The area of the spaces between zones, from which heat is also lost, was evenly divided between adjacent zones. Table I lists the areas of the zones.

Heat Transfer from the 3-Zone Head

A series of measurements of heat transfer to moving air was carried out. For some of these experiments the surface of the model head was the bright aluminum foil tape which has an estimated emissivity, ε, of 0.04 (2). The surface was cleaned with 70% isopropanol each day before experiments began. Another series of measurements was carried out after the surface had been spray painted with aluminum primer (Armor Coat, Flash Primer) to give it a high emissivity (ε = 0.85 to 0.95 (8)).

Experiments were performed in the Cold/Dry Chamber of the DCIEM Climatic Suite, which is a closed circuit wind tunnel. The test area is 15 metres long, 4.3 metres wide and over 3 m in height. The thermal manikin head was affixed to a laboratory stool 80 cm high, and placed on the centre line of the chamber, 10 metres from the flow straighteners of the windward wall (Figure 1).

 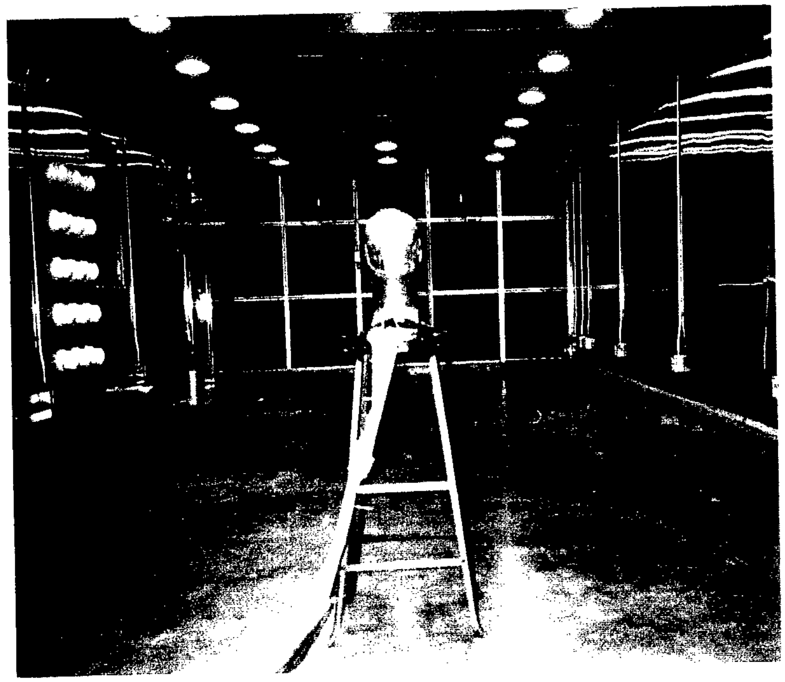

Figure 1. Two views of the three-zone thermal manikin head in the DCIEM wind tunnel.

The chamber refrigeration system was not used. Air temperature varied from day to day, but changed very little during measurement runs because of the chamber's large heat capacity. To avoid heating the room or the thermal manikin head, the lights were not turned on. When the large motor of the wind turbine was running at high speed, the air temperature drifted slowly upward at a rate of a few tenths of a degree C per hour. However, the thermal manikin head responded very quickly by comparison so a good approximation of steady state could be obtained.

Measurements were performed in still air (natural convection) and in wind (forced convection), with the thermal manikin head facing the wind. The wind speed was measured by removing the head and stool and placing the measurement head of an Air Flow Developments rotating vane anemometer (EDRA6) in its place, at the height of its nose. Because the chamber is almost isothermal, there could not have been much air movement in the chamber during the still air tests. It is also not connected to the building heating or cooling systems and the fresh-air vent system was closed.

A copper-constantan thermocouple placed 30 cm in front of the head, at stool height (80 cm) measured the air temperature. The measurement junction was covered with low emissivity aluminum tape to minimize

radiant heat transfer from the heated surfaces of the model head. The reference junction was maintained at 0 °C ± 0.02 °C by a Kaye Instruments Ice Point Reference.

Temperatures were measured every 7 to 8 seconds. Every 30 seconds, the electrical power to each zone was adjusted by a PID controller to obtain a surface temperature of 36.00 ± 0.02 °C. Each test lasted two hours. A satisfactory steady state in still air was attained in the first hour. Less time was required in wind. The last 60 values of heater power, taken during the final half hour of the two-hour period, were averaged to obtain the steady state heat loss from each zone.

Zone heat losses at steady-state, Q_i, were determined from mean heater voltages and resistance:

$$Q_i = V_i^2/R_i \qquad [1]$$

The thermal resistances, I_i, between the surface of each zone of the three-zone head and the environment were calculated from equation [2],

$$I_i = A_i\,(T_i - T_{air})/Q_i \qquad [2]$$

where A_i is the area of zone i, in m^2 and T_i is its surface temperature.

There are no previous measurements of heat transfer from the face or scalp with which the zone heat transfer coefficients of the new thermal manikin head can be compared. However, we can mathematically treat the device as if it were a single-zone thermal manikin head in order to calculate heat transfer coefficients for the whole head. As the T_i were all the same, within 0.04 °C, the overall thermal resistance experienced by the model head can be defined as:

$$I = A_{total}\;\Delta T/\Sigma Q_i \qquad [3]$$

It is often more convenient to use the total heat transfer coefficient, h, which is just the inverse of I. Heat loss from the neck segment, which acted as a guard, was not included in these calculations.

Natural Convection

Even in still air there is convective heat transfer. An object that is warmer than the air in which it sits heats the air immediately surrounding it. This warmed air is buoyant and rises, to be replaced by cooler air. The resulting flow of air is termed natural or free convection. It has been estimated that for this geometry, natural convection should account for less than 5% of the heat transfer when the wind speed is greater than 1.35 m/s

(6,9). Heat transferred by natural convection in otherwise still air can be estimated from the empirical equation for the heat transfer coefficient of a vertical cylinder in still air (9):

$$h_{free} \approx 0.59(k_{air}\, L)\ (Pr\ Gr)^{1/4} \qquad [4]$$

where L is the height of the cylinder, Pr is the Prandtl number for air, k_{air} is the thermal conductivity of air and Gr is the non-dimensional Grashoff number. The latter is given by:

$$Gr = gL^3\ (T - T_\infty)/T_\infty\, \upsilon^2 \qquad [5]$$

where g is the acceleration due to gravity, T is the surface temperature, T_∞ is the temperature (°K) of the air far from the heated cylinder and υ is the kinematic viscosity. A characteristic height of 0.25 m may be used for L.

Using equations [4] and [5], the predicted natural convective heat transfer at zero wind speed is 3.8 W/m^2K. The measured value, in still air, was 4.4 W/m^2K. A slight movement of air in the chamber (less than 0.02 m/s) could account for the small difference, however, perfect agreement should not be expected as the head is more complex than a simple cylinder.

The surface temperatures of the zones were all set to the same value, to minimize heat transfer between zones. To minimize the effect of chamber temperature drift during an experiment or from day to day, this temperature was set to be a constant number of degrees higher than the air temperature. An increment of 10 °C was arbitrarily chosen. If the surface temperature of the device were set at a constant value, $T - T_\infty$ would vary with the chamber temperature. From equation [5], the Grashoff number and therefore the heat transfer coefficient in still air could then be different on different days. The variation in the still air test values was less than 5%.

Radiative Heat Transfer

There is some radiative heat transfer from even a shiny metal surface. Because radiative heat transfer is approximately linearly proportional to the temperature difference, a radiant heat transfer coefficient, h_r, can be defined. For a small object in a large enclosure it is (9):

$$h_r \approx 4\varepsilon\sigma T^3 \approx 0.25\ m^2\ K/W \qquad [6]$$

where ε is the emissivity of shiny aluminum foil, i.e. 0.04 (2), σ is the Stefan-Boltzmann constant, 5.67 x 10^{-8} W/m^2K^4 and T is the mean of the absolute surface temperatures of the model head and the chamber. The chamber

surface temperatures were not measured, but since the chamber was well-insulated, they were assumed to be equal to the air temperature. Because of the heat capacity of the walls, this introduces a small source of error at high wind velocities when the heat of the turbine causes the air temperature to increase. However, at high wind speeds, the radiative heat transfer is less important.

When the emissivity of the surface was low, the total heat transfer coefficient in "still" air was 4.7 W/m^2K. When painted, the total heat transfer coefficient increased to 9.4 W/m^2K. Since the surface and air temperatures had not changed, this could only be due to an increase of 4.7 W/m^2K in the radiative heat transfer coefficient from its initial value of 0.25 W/m^2K when unpainted. The radiative heat transfer coefficient of the painted surface was therefore approximately 5.0 W/m^2K.

Equation [6] must be modified for an object that "sees" part of its own surface. The radiating area of an object like a thermal manikin head is less than its actual surface area, because some parts of the face, such as the nose, exchange radiation with other parts of the face as well as with the chamber. Equation [6] can be altered and then rearranged to read:

$$f_r \varepsilon \approx 5.0 / (4\sigma T^3) \qquad [7]$$

where f_r is the fractional radiating area. The product of emissivity and fractional radiating area of the painted model head works out to be 0.8. A measurement of the emissivity of a similarly painted surface having no projections or concavities would be required to characterize these parameters separately.

Forced Convection

When the heat transfer coefficients calculated from experiments with the high and low emissivity surfaces are corrected for radiative exchange, they collapse to a single curve, as in Figure 2.

The best-fit curve in Figure 2 was calculated using data at wind speeds higher than 1.4 m/s so that the influence of natural convection would be minimized. A simple equation fits the data points quite well (r^2=0.995):

$$h_c = 11.5\ V^{0.68} \qquad [8]$$

This equation can be expressed in non-dimensional terms as:

$$Nu = 0.142\ Re^{0.68} \qquad [9]$$

where Nu is the Nusselt number ($h_c D/k_{air}$) and Re is the Reynolds number (VD/υ), k_{air} is the thermal conductivity of air, υ is its kinematic viscosity, at the mean of air and surface temperatures and D is equal to the width of the model head at its widest point, 16.2 cm. This equation describes the effect of wind speed on the forced convective heat transfer coefficient of an object of the shape of a human head, from a Reynolds number of 15,000 to at least 77,000.

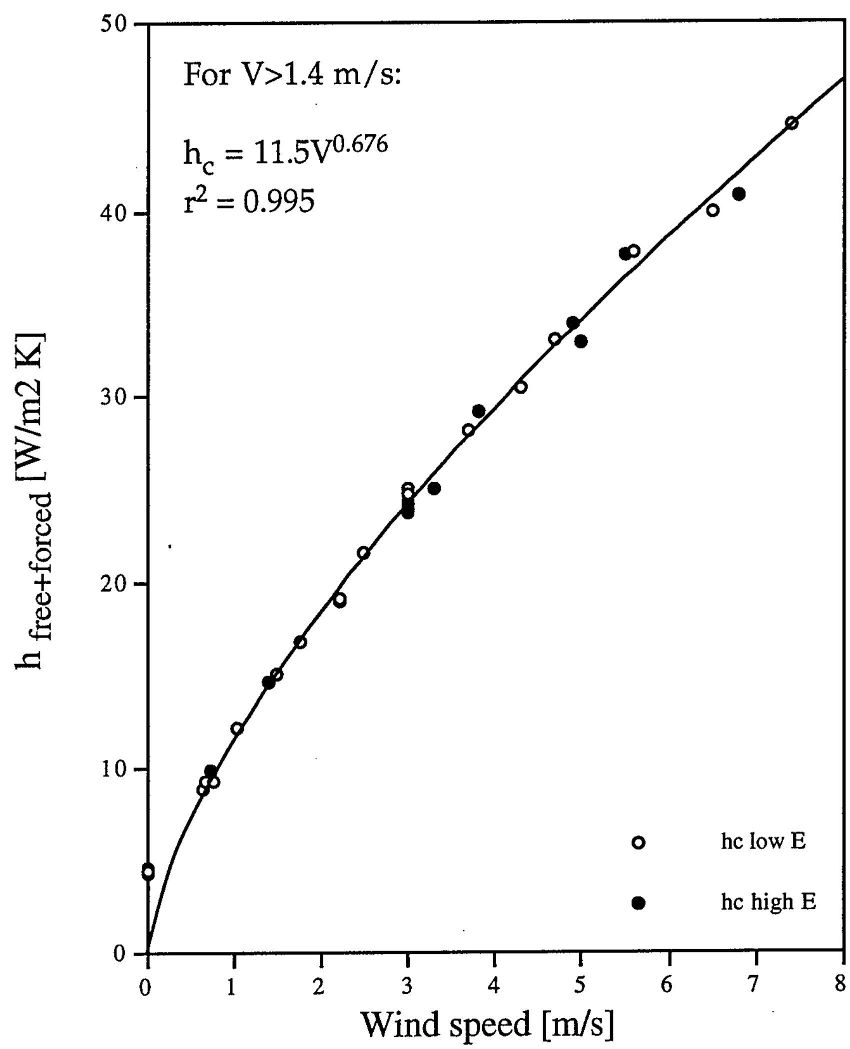

Figure 2. Convective heat transfer coefficients for the three-zone head with high and low emissivity surfaces.

Because the data points at lower wind speeds do not depart significantly from the forced convection curve, it would seem that natural convection is not significant even at 1 m/s.

Discussion

In Figure 3, the whole-head heat transfer coefficients are compared to results from similar experiments with the head sections of two other thermal manikins, and with data for the human head. The three-zone thermal manikin head (3-Z head) falls between the heat transfer from the CORD (4,5) thermal manikin (TIM) and an early version of USARIEM's Copper Man (7).

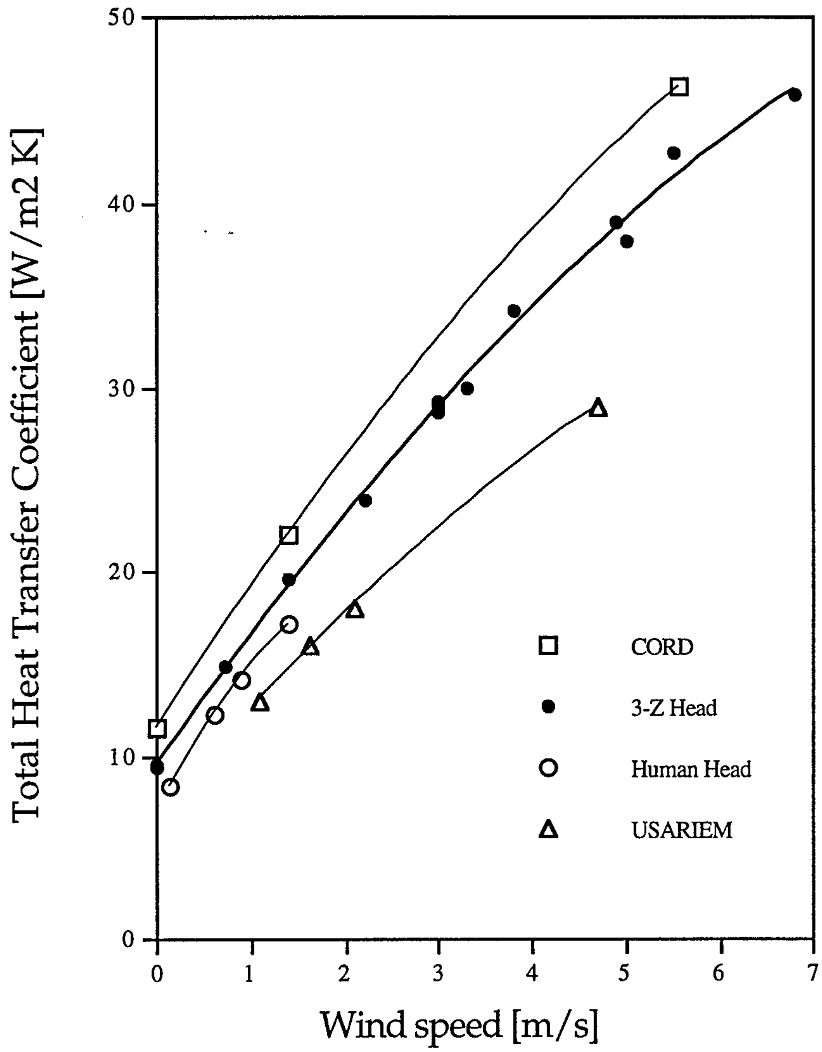

Figure 3. Heat transfer from the three-zone thermal manikin head compared to values obtained from the heads of two other thermal manikins and from human subjects.

Differing degrees of turbulence in the air streams of the respective wind tunnels might account for much of the difference between manikin heads. The heat transfer at any wind speed appears to be inversely related to wind tunnel size and sophistication. The CORD wind tunnel, which has

since been redesigned, was 7.3 metres in length had an array of six large exhaust fans standing less than 4 metres from the manikin. Air flow in this wind tunnel might have been more turbulent, causing the higher hèat transfer coefficients. When the DCIEM wind tunnel was made more turbulent by turning on the blowers of the refrigeration system, the convective heat transfer increased by about 25% at each of three wind speeds used in this experiment.

The Sir Hubert Wilkins Arctic Wind Tunnel at USARIEM is the largest of the three. It is 18.3 m long, 4.6 wide and 3.7 m high. The USARIEM Copper Man had the lowest heat transfer coefficient at a given wind speed, which might reflect a less turbulent air flow. However, the difference could also have been due to a reduced radiative heat transfer from the manikin's cotton skin, which might have had an emissivity that was significantly less than 1. Although their experiments were performed with the wind at the manikin's back, this orientation would not have made a large difference in the whole-head heat transfer coefficient.

Values for the human head are also shown in Figure 3. These were inferred by Clark and Toy (3) from measurements on two subjects. In light winds, Clark and Toy found that local heat transfer coefficients around the head varied in a manner that was similar to the pattern of heat loss around the circumference of a vertical cylinder. They derived their whole-head convective coefficients from local values by assuming the head was a cylinder. To obtain total heat transfer coefficients for Figure 3, a radiative heat transfer coefficient of 5.0 W/m^2K has been added.

Although the heater and sensor wires are fine, and are covered with several layers of aluminum, the "skin" is not smooth. There are a series of comparatively widely spaced ridges approximately 1 mm high. Many of these ridges are roughly parallel to the direction of air flow. These irregularities do not affect the convective heat transfer. Achenbach (1), experimented with 15 cm diameter cylinders of a range of surface roughness in a wind tunnel and found that the heat transfer coefficient varied with Reynolds number to the power 0.63 when the Reynolds number was below a critical value that depended on roughness. For a smooth 15 cm diameter cylinder, the critical Reynolds number was 200,000. With roughness elements of about the same height (0.9 mm) as those of the model head, but much more densely coving the surface, this critical Reynolds number was about 57,000. At higher flows, heat transfer actually decreased because more of the surface was covered by a laminar boundary layer having a substantial resistance to heat flow. When the flow was increased further, the boundary layer became turbulent, causing almost a step increase in heat transfer over critical levels. Because these features are not evident in the data from the three-zone head experiments, it is apparent that its critical Reynolds number had not been reached. The

convective heat transfer from the three-zone thermal manikin head was therefore not affected by its surface roughness.

Conclusion

Because the new thermal manikin head has three zones, the local effects of wind on heat loss from any zone can be determined separately. The device can therefore be used to measure the actual thermal insulation of face masks, helmets or other items of headwear that cover areas corresponding to the measurement zones. Insulation values obtained with single-zone manikin heads include heat transfer from large areas of the head that the item does not cover.

Heat transfer coefficients for the whole head, obtained by treating the three-zone head mathematically as a single-zone device, compare very well with those obtained from the heads of established thermal manikins and from the human head. An equation was derived that relates the convective heat transfer of the whole head to the wind speed, over a range from about 1m/s up to 7.3 m/s. A similar equation will be derived for heat transfer from just the face in wind. This information will be used to investigate wind chill.

Acknowledgements

I wish to thank Brad Cain and Walter Dyck, whose advice and assistance facilitated the interfacing of the various elements of the measurement and control systems of the three-zone thermal manikin head with the computer.

References

(1) ACHENBACH, E., 1977. The effect of surface roughness on the heat transfer from a circular cylinder to the cross flow of air. International Journal of Heat and Mass Transfer, **20**, pp. 359-369.

(2) CAIN, J. B., N. MCKAY, 1991. Thermal radiative properties of metallized films, Journal of Thermal Insulation, **14**, p 221-239.

(3) CLARK, R. P., TOY, N., 1975. Forced convection around the human head. Journal of Physiology **244**, p 295-302.

(4) CORD GROUP LTD., 1990. Contract Report. Thermal evaluation of prototype cold weather clothing and current CF cold weather clothing, for Defence Research Establishment Ottawa, Department of National Defence, Ottawa.

(5) CORD GROUP LTD., 1991. Contract report. Final report on the thermal evaluation of NBC clothing ensembles, for Defence Research Establishment Ottawa, Department of National Defence, Ottawa.

(6) DANIELSSON, U., 1993. Convection coefficients in clothing air layers, doctoral thesis, Department of Energy Technology, Division of Heating and Ventilation. The Royal Institute of Technology, Stockholm, Sweden and the Department of Human Studies, National Defence Research Establishment, Sundbyberg, Sweden. ISSN 1104-3008.

(7) FONSECA, G., 1975. Sectional Dry-Heat-Transfer Properties of Clothing in Wind. Textile Research Journal, **45**, 30-34.

(8) MACPHEE, C. W., 1972. ed. ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers, New York.

(9) SISSOM, L. E., D. R. PITTS, 1972. Elements of Transport Phenomena, McGraw-Hill Book Company, New York.

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A thermal model of a human head was constructed from a rigid polyurethane foam headform with a skin of aluminum. Its surface is divided into three zones: the scalp, face and a small forehead/ears zone. The surface temperature and heat loss from each zone are individually controlled and monitored by a computer. Because it has independent zones that more closely correspond to the areas covered by helmets or face masks, the three-zone thermal manikin head is better suited to the measurement of the thermal insulation of headwear than a manikin head that has only one measurement zone. Single-zone heads measure the effective thermal resistance of the whole head, which usually includes large areas not covered by the item in question.

Heat transfer from the entire manikin head was measured in a wind tunnel at wind speeds up to 7.3 m/s (26 km/h). The results compared favourably with whole head heat transfer from the head segment of other thermal manikins and from the human head. An equation was derived to describe the effect of wind on heat loss. The radiative heat transfer coefficient was also determined.

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CONVECTION
CONVECTIVE HEAT TRANSFER
EMISSIVITY
ENVIRONMENTAL PHYSICS
FACE
FACE MASK
HEAD
HEADWEAR
HEAT LOSS
HEAT TRANSFER COEFFICIENT
MANIKIN
SCALP
TESTING
THERMAL INSULATION
THERMAL MANIKIN
THERMAL MANNEQUIN
THERMAL RADIATION
THERMAL RESISTANCE
WIND
WIND CHILL